

# TECHNICAL NOTE

D-1227

A BRIEF EVALUATION OF HELICOPTER WAKE AS A  
POTENTIAL OPERATIONAL HAZARD TO AIRCRAFT

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## SUMMARY

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A number of incidents of encounters with severe turbulence occurring in the general vicinity of operating helicopters have been reported by pilots, specifically in airport traffic situations. In relation to this problem flight tests were conducted with an airplane and a single-rotor helicopter to determine some characteristics of the helicopter wake and its possible upsetting tendencies on an airplane. A sample procedure for estimating important wake characteristics is also included.

Flight tests with the airplane and helicopter have shown that helicopter wake presents a potential hazard to aircraft operating near the wake. Suggested operating precautions to minimize the hazard potential of a helicopter wake include reminding pilots of aircraft following a helicopter to remain above the helicopter flight path and, if in doubt about relative positions, to extend the separation interval between aircraft. An exact time interval was not determined, but a separation estimated to be about 1 minute appears to be a reasonable time with most of the present generation helicopters.

## INTRODUCTION

A number of incidents of encounters with severe turbulence occurring in the general vicinity of operating helicopters have been reported by pilots, specifically in airport traffic situations. Although the reported turbulence could not positively be attributed to the helicopters, the reporting pilots suspected the helicopter wake to be its source.

Operational problems related to fixed-wing aircraft wake and its effects on other aircraft have received considerable attention both experimentally and analytically as, for example, references 1 and 2. The average velocity and the total energy of the downwash in a helicopter wake are similar to those for an airplane of the same weight and span and flying at the same airspeed. The differences in local velocities

for the helicopter and airplane, however, are sufficient to warrant some separate study of the helicopter. Also, the helicopter downwash velocities do not increase, as hovering is approached, to the extent which could be inferred if an airplane of the same weight and span were considered to be operating at speeds approaching hovering.

A theoretical analysis of helicopter rotor downwash with wind-tunnel verification is presented in reference 3. Reference 3 also describes the wake downstream from the rotor in terms of downwash contour gradients but does not relate its results specifically to the operational problem of helicopter wake as a potential hazard to aircraft.

This paper will discuss some characteristics of the wake of a helicopter and illustrate the possible upsetting tendencies on an aircraft some distance behind the helicopter. Actual flight tests were performed in which an airplane penetrated a helicopter wake at flight conditions selected to be typical in airport traffic situations. Also, a simple method for calculating downwash velocity in hovering and the intensity and deflection angle of the wake of a helicopter in forward flight will be illustrated.

#### SYMBOLS

$C_T$	thrust coefficient, $\frac{T}{\pi R^2 \rho (\Omega R)^2}$
$R$	rotor radius, ft
$T$	thrust, lb
$V$	velocity, ft/sec
$v$	local downwash velocity, positive down, ft/sec
$v_h$	hovering downwash velocity, positive down, ft/sec
$v_o$	rotor induced velocity, positive down, ft/sec
$\Omega$	rotor angular velocity, radians/sec
$\alpha$	rotor angle of attack, deg
$Y$	distance parallel to lateral rotor-tip path plane axis, positive on advancing side of rotor, ft

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Z	distance parallel to axis perpendicular to rotor-tip-path plane, positive above rotor center, ft
$\lambda$	induced-velocity ratio, $\frac{V \sin \alpha - v_o}{\Omega R}$
$\Delta a_n$	incremental accelerations in normal direction, g units
g	acceleration due to gravity, ft/sec <sup>2</sup>
$\theta_n$	wake deflection angle, measured downward from the horizontal, deg
$\rho$	density of air, standard, 0.002378, slug/ft <sup>3</sup>
$\mu$	tip-speed ratio, $\frac{V \cos \alpha}{\Omega R}$
$\frac{T}{\pi R^2}$	mathematical expression known as "disk-loading," comparable to term "wing loading" on fixed-wing aircraft

#### TEST EQUIPMENT AND TEST PROCEDURE

The single-rotor helicopter shown in figure 1 was used to generate the wake and the airplane shown in figure 2 was used to penetrate the wake for this study. The principal dimensions and physical characteristics of these aircraft are listed in tables I and II. Colored smoke was streamed into the wake as an identification device. Figure 3 shows one of the outrigger booms installed on the helicopter for carrying as many as 36 smoke grenades.

Recording instruments installed in the airplane were an accelerometer to measure normal accelerations at the center of gravity of the airplane and a lateral control position transmitter to measure pilot control inputs. All other in-flight variables, such as airspeed, altitude, heading, and bank angle were indicated on the normal instrument display of the airplane. No recording instruments were installed in the helicopter, and in-flight variables were also indicated on the helicopter instrument display.

In the penetration flight tests, the airplane was operated at 80 knots (and 10° flaps), and the helicopter at 40 knots. The helicopter was held on a constant heading and altitude (4,000 feet). The wake penetrations consisted of (a) converging penetrations where the airplane gradually crossed through the helicopter wake from a course nearly parallel to that of the helicopter, (b) descent through the wake on the same

heading as the helicopter, and (c) intersecting penetrations from a course  $90^\circ$  to the helicopter heading. The first two types of penetration would more likely be encountered operationally where both the airplane and helicopter are directed over the same approach path.

In order to obtain an indication of wake drift over a flight path, the helicopter was flown at an altitude of 150 feet and 50 knots on a course  $90^\circ$  to the surface wind. The flight path and the approximate wind course were staked out on the ground at 100-foot intervals with appropriate markers. The movement of the smoke wake referenced to the markers was then documented by continuous-recording, constant-speed movie cameras.

## RESULTS AND DISCUSSION

### Flight-Test Results

Airplane penetrations into the helicopter wake.- The first type of penetration test to be discussed is the converging type in which the pilot applied corrective control to avoid lateral upset. The airplane penetrated the wake approximately 1,000 feet behind the helicopter at 50, 100, and 200 feet below the helicopter flight path. The wake is represented schematically in figure 4 to illustrate in general the flow field the airplane encountered during a penetration.

Time histories of normal accelerations and of the pilot control inputs during these penetrations are shown in figure 5. The penetration from 50 feet below the helicopter flight path (fig. 5(a)) required only minor corrective action. The next case (fig. 5(b)), from 100 feet below the flight path, was more severe. The penetration at 200 feet below the flight path (fig. 5(c)) required extreme corrective action. In the latter case the pilot was required to use about 90 percent of the total available lateral control in less than a half second to maintain nearly level flight. Calculations indicate that a control input of this magnitude in calm air at the test flight conditions would result in a rate of roll of approximately  $36^\circ$  per second.

Converging penetrations were also made during which the pilot held the stick fixed and permitted the airplane to be upset. In one case at about 1,000 feet behind the helicopter the airplane was upset to a roll angle of about  $40^\circ$ . In another penetration about 1,500 to 2,000 feet behind the helicopter a  $25^\circ$  roll angle was noted. The altitude of the airplane below the flight path of the helicopter was not recorded in either of these cases.

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A landing-approach penetration was simulated by a descent at 250 feet per minute on course through the wake. The penetration was, again, about 1,000 feet behind the helicopter. As the airplane entered the wake, moderate but pronounced rolling occurred and the rate of descent increased to 500 feet per minute.

No outstanding effects were noted during this investigation in the perpendicular penetrations executed at various distances downstream from the helicopter rotor. Normal acceleration increments at the airplane center of gravity of  $\pm 0.3g$  were recorded about 600 feet behind the helicopter. However, the results of reference 2 indicate that much larger load factors are attainable from a wake of the intensity generated by the test helicopter.

Wake drift.- Documentation of the wake drift under the influence of moderate crosswinds was undertaken in order to determine the hazard potential of a helicopter laying down a wake over an approach path. Figure 6 shows time-history plots of the wake drift during a 2-knot and an 8-knot surface wind blowing from approximately  $90^\circ$  to the flight path. In both cases the wake appeared to drift with the wind after initial vortex expansion. Although crosswind drift was fairly well documented in these tests, movement within the wake after some elapsed time was not clear from the smoke tests. It is considered possible that the wake velocities decay more rapidly after the wake fringes reach the ground, but the test techniques gave no information on this point.

### Wake Description

In the preceding section the qualitative effects of helicopter wake on a fixed-wing airplane were described in terms of lateral upset encountered by the airplane. The upset is caused by the rotor-generated vortices in the wake, a flow similar to that which occurs in the wake of fixed-wing airplanes. In the airplane case, air rolls up around the wing tip from the underside of the wing and forms a vortex core. The wake picture is essentially the same for a helicopter rotor at some forward velocity. (The velocity must be distinctly removed from hovering.) The intensity of the wake is related to the vortex strength which depends upon the energy the aircraft imparts to the air; this, in turn, is a function of the geometry and airspeed of the aircraft in question.

### Wake Intensity

In order to obtain an estimate of the relative wake intensity the rotor downwash velocity  $v_o$  (eq. (A2a)) can be directly applied to figure 7, which is a plot of the vortex velocity contours within the

wake. This figure, obtained from reference 3, shows the wake contours at 3.14 rotor radii behind the rotor center as a ratio of the average in-plane rotor velocity. The rotor wake has fully developed at this stage. Thus to obtain the local velocity at any point in the wake, multiply the value for  $v_0$  by the number shown on the contour curves. Figure 8 is an application of this technique. The downwash velocity  $v_0$  for 45 knots (to agree with the conditions selected for the figure in ref. 3) was calculated and multiplied by the contour ratios along the plane of the vortex cores. The direction and magnitude of the vortex velocities from one side of the wake to the other as sources of airplane upset are thus readily apparent. Notice, also, that the contour gradients of figure 7 indicate upward direction with a negative sign in keeping with rotor-theory sign convention.

When helicopters of increased size and weight are considered, if the disk loading and airspeed are kept the same, the wake will simply become larger as the rotor becomes larger, with the same downwash velocities as for smaller helicopters. (Disk loading on the helicopter is analogous to the ratio of weight to span-squared on an airplane.) Larger helicopters commonly tend to have higher disk loading, however, and if for this or any other reason the disk loading is increased, then at any given airspeed the downwash velocity and thus the wake intensity will increase. Specific cases may be examined by following the procedure given in the appendix.

#### Pilot Comments

The penetration flight tests of this study were performed by a research pilot accompanied by an observer. In the pilot's opinion, crossing through the wake center can produce lateral upsets that would be dangerous if occurring near the ground. The pilot further commented that the limits of lateral control were slightly exceeded for the airplane used in these penetration tests. The test airplane was a military trainer which meets the roll control requirements of the military handling qualities specifications. (See ref. 4.)

One of the observer's tasks was to measure with a stopwatch the time interval from wake penetration until the airplane passed by the helicopter in order to obtain distance estimates. Several attempts were made to test the wake intensity at extended distances behind the helicopter. Comments from both the pilot and observer indicated that, when the separation interval was on the order of a minute, the airplane encountered only minor turbulence. However, neither the pilot nor observer was sure whether the low intensity encountered at this interval was due to wake dissipation or smoke dispersion either of which would cause the wake location to be uncertain.



### Operating Precautions

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In reviewing the flight-test results and the pilot commentary on the flights, it is believed that operating precautions to minimize the hazard potential of encounters with helicopter wake can be taken. It is important to remember not to fly below the flight path of a leading helicopter during an approach, and the following aircraft should remain on or above the flight path of the leading helicopter. Should doubts exist concerning the relative approach paths of a lead helicopter and a following aircraft, the following aircraft would be advised to extend the separation interval between them. An exact time interval was not determined in these tests, but a separation of about 1 minute tentatively appears to be a reasonable time with most of the present generation helicopters.

Operators of the low-wing-loading, private-owner-type airplane should probably observe the above suggested precautions with extra care. Although no tests were performed with this type of airplane for this study, it is believed that the wake would be a greater potential hazard to this type of airplane than it was shown to be in these trials with the test airplane.

### CONCLUDING REMARKS

Limited flight tests of a fixed-wing airplane in the wake of a single-rotor helicopter have shown that the helicopter wake is of sufficient intensity to be a potential operational hazard, particularly in regard to airport traffic situations. Although low-altitude penetration tests were not performed, the hazard potential of the helicopter wake is expected to be greater at low speeds and low altitudes such as in the final approach to a landing. Also, helicopters with greater disk loadings would produce wakes of greater intensity at a given speed, regardless of their size, and larger helicopters with no increase in disk loading would produce wakes enlarged only in size.

Suggested operating precautions to minimize the hazard potential of a helicopter wake include reminding pilots of aircraft following a helicopter to remain above the helicopter flight path, and, if in doubt about position, to extend the time interval between aircraft. An exact time interval was not determined, but a separation estimated to be about 1 minute is tentatively suggested as a reasonably safe interval with most of the present generation helicopters.

Operators of the low-wing-loading, private-owner type of airplane should probably observe the suggested precautions with extra care.

Langley Research Center,  
National Aeronautics and Space Administration,  
Langley Air Force Base, Va., January 8, 1962.

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## APPENDIX

## CALCULATIONS OF WAKE INTENSITY

## Downwash Calculations in Hovering

The helicopter wake is produced by the rotor downwash. Based on momentum theory, the simplest equation for calculating the average downwash velocity is given in reference 5 for hovering flight as:

$$v_h = \sqrt{\frac{T}{2\pi R^2 \rho}} \quad (A1)$$

where

T thrust or normal gross weight, 6,900 lb

R = 26.5 ft; thus  $\pi R^2 = 2,207$  sq ft

$\rho = 0.002378$  at sea-level standard conditions

Therefore,

$$\frac{T}{2\pi R^2 \rho} = \frac{6,900}{(2)(2,207)(0.002378)} = 657 \text{ ft}^2/\text{sec}^2$$

$$v_h = \sqrt{657 \text{ ft}^2/\text{sec}^2}$$

$$v_h = 25.6 \text{ ft/sec}$$

This equation yields the average induced velocity at the plane of the hovering rotor. The slipstream contracts within half a rotor diameter to half the rotor area, and the final downwash velocity becomes twice the velocity in the rotor plane. The final downstream hovering downwash velocity is then equal to  $2v_h$  or 51.2 feet per second.

## Downwash Velocity in Forward Flight

Average rotor downwash velocity at the rotor plane in forward flight is obtained from reference 5,

$$v_o = \frac{\frac{1}{2} C_T \Omega R}{\sqrt{\lambda^2 + \mu^2}} \quad (A2)$$

which can be reduced to

$$v_o = \frac{T}{2\pi R^2 \rho V} \quad (A2a)$$

at forward speeds where  $0.1 < \mu < 0.2$  which is a range of 30 to 60 knots for the test helicopter.

By using the flight-test speed of 40 knots in level flight as a representative flight condition, equation (A2a) is solved thusly:

From equation (A1)

$$\frac{T}{2\pi R^2 \rho} = 657 \text{ ft}^2/\text{sec}^2$$

At 40 knots,

$$V = 67.6 \text{ ft/sec}$$

thus,

$$v_o = \frac{657 \text{ ft}^2/\text{sec}^2}{67.6 \text{ ft/sec}}$$

$$v_o = 9.7 \text{ ft/sec}$$

As in the hovering case, the average downwash velocity is twice the in-plane rotor velocity.

#### Graphic Solution

Reference 6 presents a graphic solution for the average induced velocities and wake skew angles of VTOL-STOL aircraft. A broad range of flight conditions is considered in reference 6, but the graph of figure 9 uses only the level-flight condition.

First, calculate hovering  $v_h$  by equation (A1); then divide  $v_h$  into the forward velocity  $V$  for the ratio  $V/v_h$ . For the test helicopter at 40 knots

$$\frac{V}{v_h} = \frac{67.6}{25.6} = 2.64$$

Locate the abscissa where  $\frac{V}{v_h} = 2.64$ ; read up on a straight line to the curve on figure 9. On the left-hand side of the figure is  $\frac{v_o}{v_h} = 0.38$ ;

on the right-hand side is  $\theta_n = 7^\circ$  or the angle of wake deflection.

Multiply  $\frac{v_o}{v_h}$  times  $v_h$  to obtain  $v_o$  which is  $0.38 \times 25.6$  or

9.7 ft/sec. Notice that this value is the same as that obtained by equation (A2a) at this particular forward speed for the particular test helicopter. As a greater range in speed is considered, the precision of equation (A2a) will diminish and use of the chart would be preferable.

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## REFERENCES

1. Kraft, Christopher C., Jr.: Flight Measurements of the Velocity Distribution and Persistence of the Trailing Vortices of an Airplane. NACA TN 3377, 1955.
2. McGowan, William A.: Calculated Normal Load Factors on Light Airplanes Traversing the Trailing Vortices of Heavy Transport Airplanes. NASA TN D-829, 1961.
3. Heyson, Harry H., and Katzoff, S.: Induced Velocities Near a Lifting Rotor With Nonuniform Disk Loading. NACA Rep. 1319, 1957. (Supersedes NACA TN 3690 by Heyson and Katzoff and TN 3691 by Heyson.)
4. Anon.: Flying Qualities of Piloted Airplanes. Military Specification MIL-F-8785 (ASG), Sept. 1, 1954; Amendment - 1, Oct. 19, 1954.
5. Gessow, Alfred, and Myers, Gary C., Jr.: Aerodynamics of the Helicopter. The Macmillan Co., c.1952.
6. Heyson, Harry H.: Nomographic Solution of the Momentum Equation for VTOL-STOL Aircraft. NASA TN D-814, 1961.

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TABLE I.- PRINCIPAL DIMENSIONS AND APPROXIMATE  
PHYSICAL CHARACTERISTICS OF TEST HELICOPTER

Gross weight, lb . . . . .	6,900
Number of blades . . . . .	3
Rotor blade radius, ft . . . . .	26.5
Flapping-hinge offset, ft . . . . .	0.75
Weight of blades (approximate), lb/blade . . . . .	136
Main rotor blade:	
Type . . . . .	All metal, constant chord
Twist, deg . . . . .	-8
Airfoil section . . . . .	NACA 0012
Blade chord, ft . . . . .	1.368
Rotor solidity . . . . .	0.0493
Approximate rotor-blade mass constant . . . . .	11
Rotor blade tip speed, ft/sec . . . . .	538
Disk loading, lb/sq ft . . . . .	3.12
Rotor angular velocity, radians/sec . . . . .	20.3
Center of gravity, inches from reference datum	
(reference datum 14.5 in. forward of nose) . . . . .	129.6

TABLE II.- PRINCIPAL DIMENSIONS AND APPROXIMATE  
PHYSICAL CHARACTERISTICS OF THE TEST AIRPLANE

[Two-place tricycle-gear military trainer]

Length, ft . . . . .	32
Height, ft . . . . .	13
Wing span, ft . . . . .	41
Normal gross weight, lb . . . . .	7,400
Wing loading, lb/ft <sup>2</sup> . . . . .	25
Take-off speed, knots . . . . .	75
Final approach speed, knots . . . . .	100
Approximate stall speed (10° flaps), knots . . . . .	65
Installed horsepower . . . . .	800

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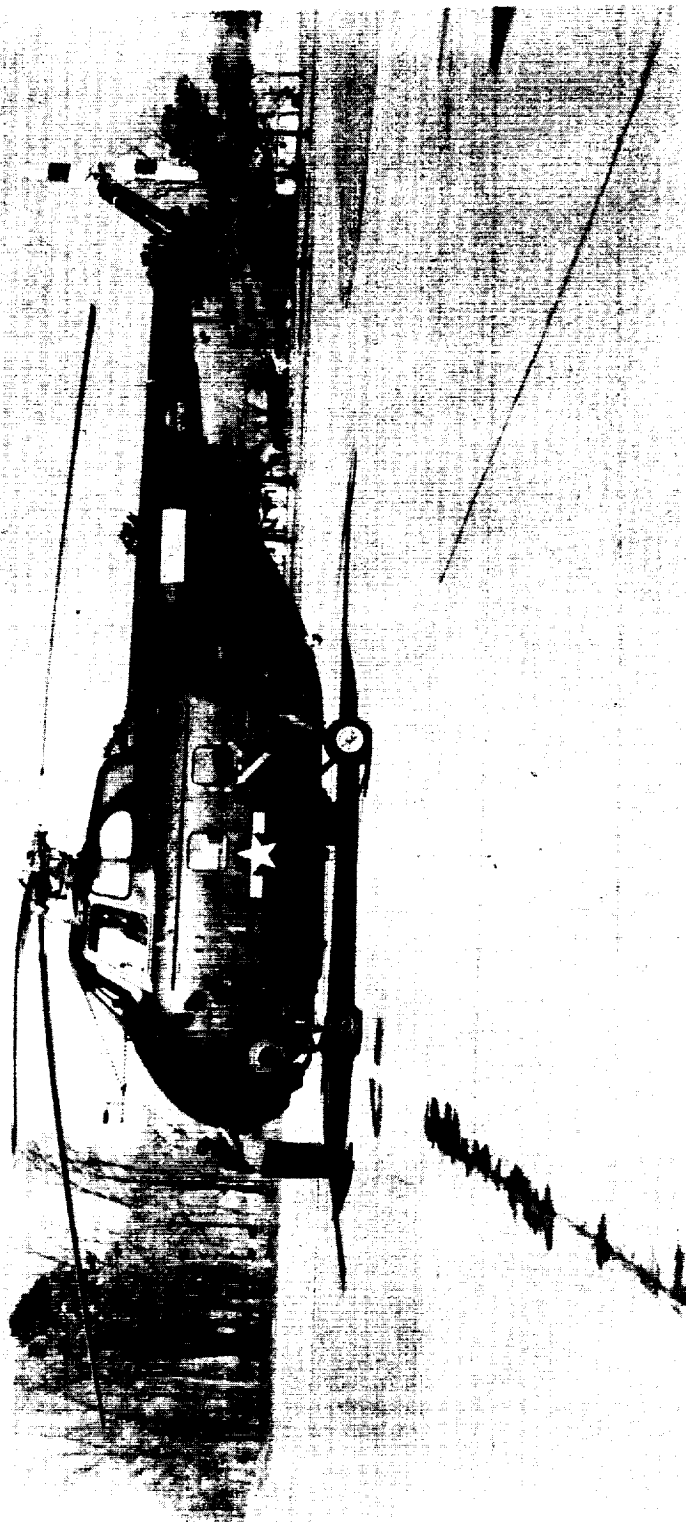


Figure 1.- Test helicopter.

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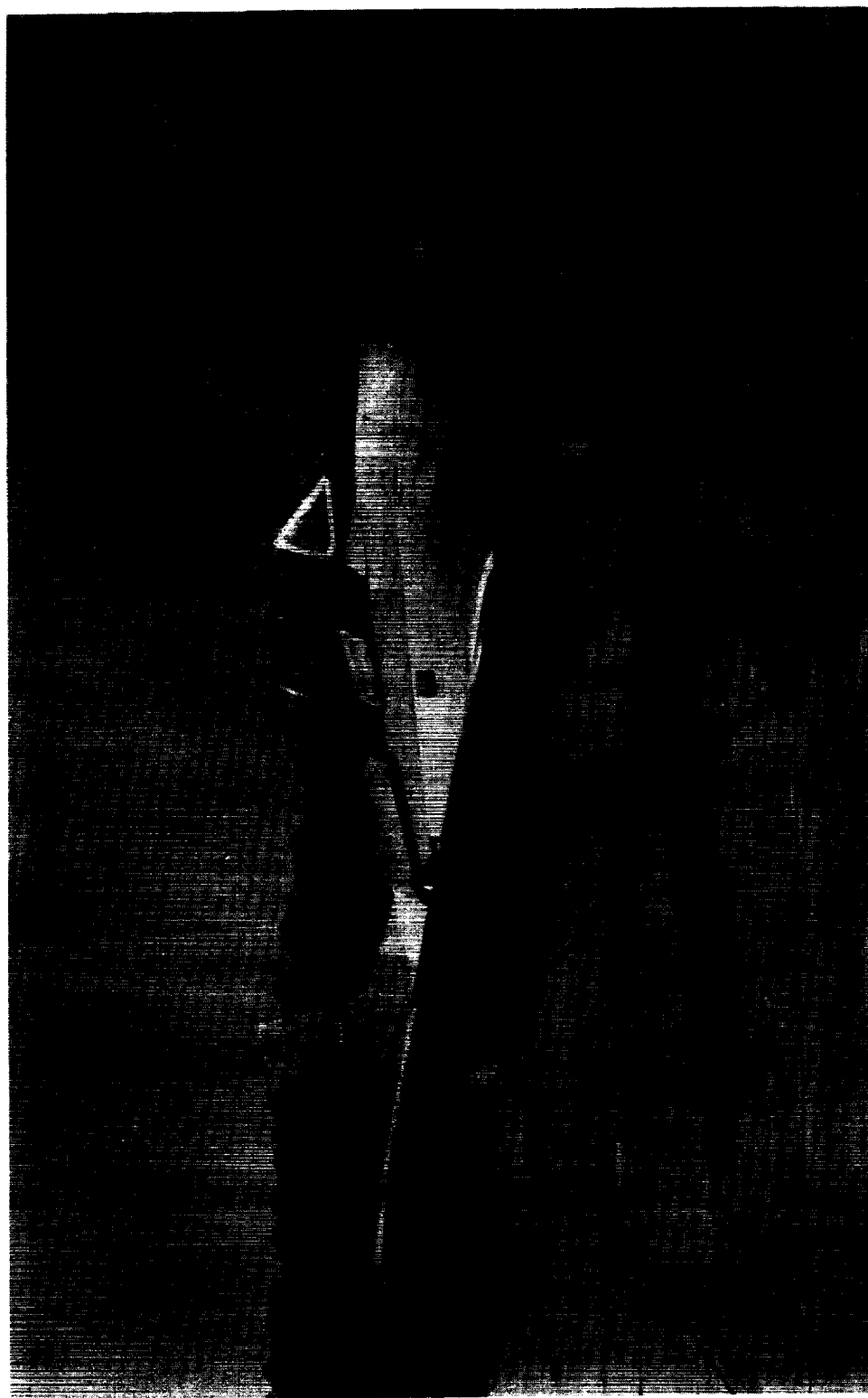


Figure 2.- Test airplane.

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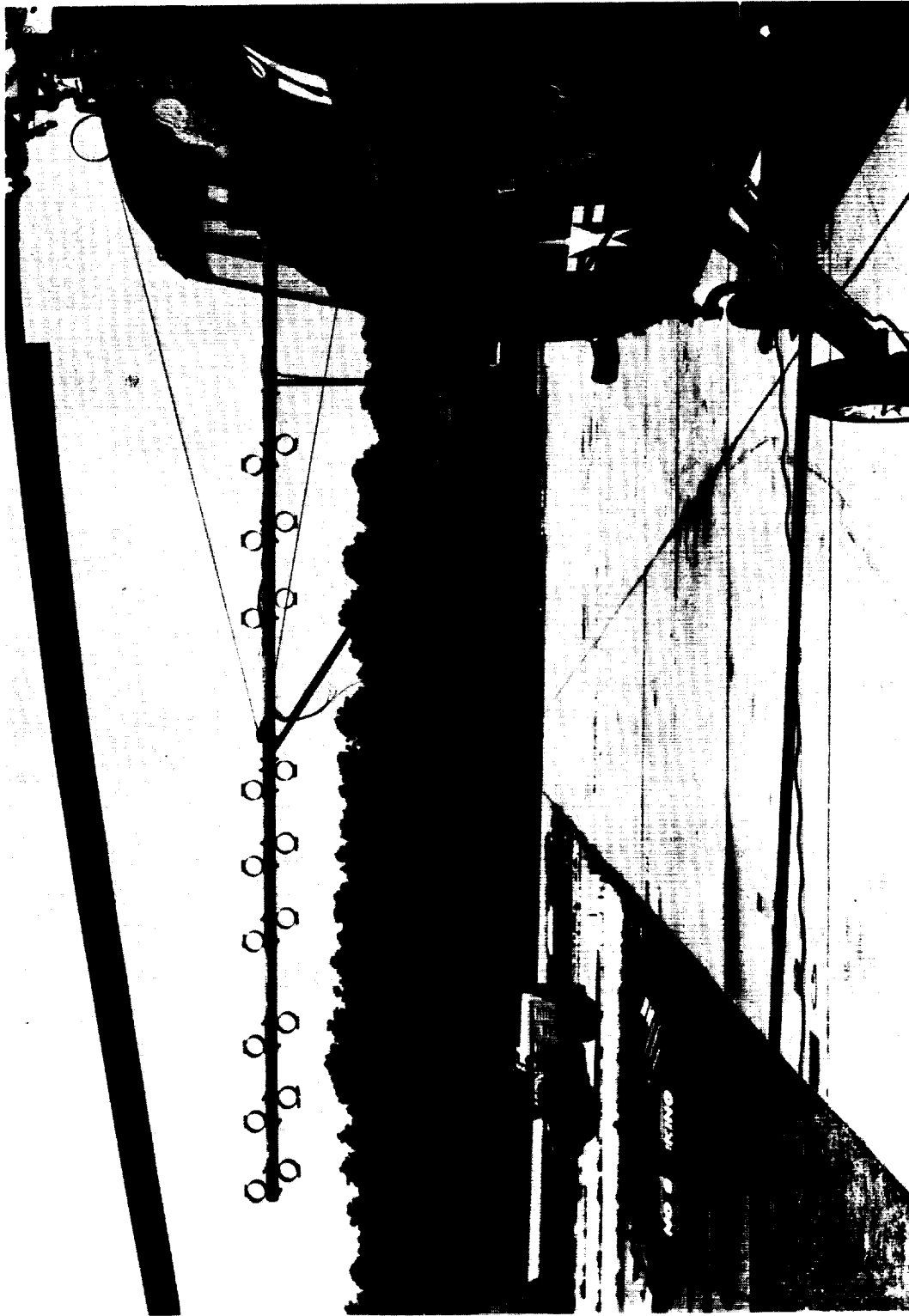


Figure 3.- Outrigger boom on the test helicopter for mounting smoke grenades. A similar outrigger is attached on the opposite side of the helicopter.

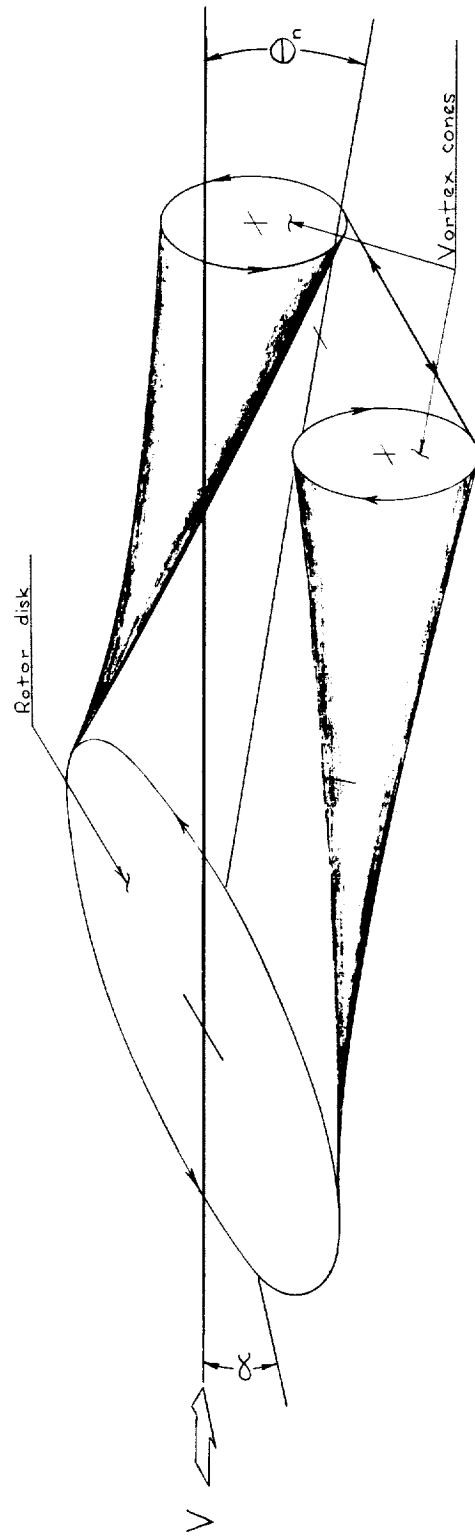
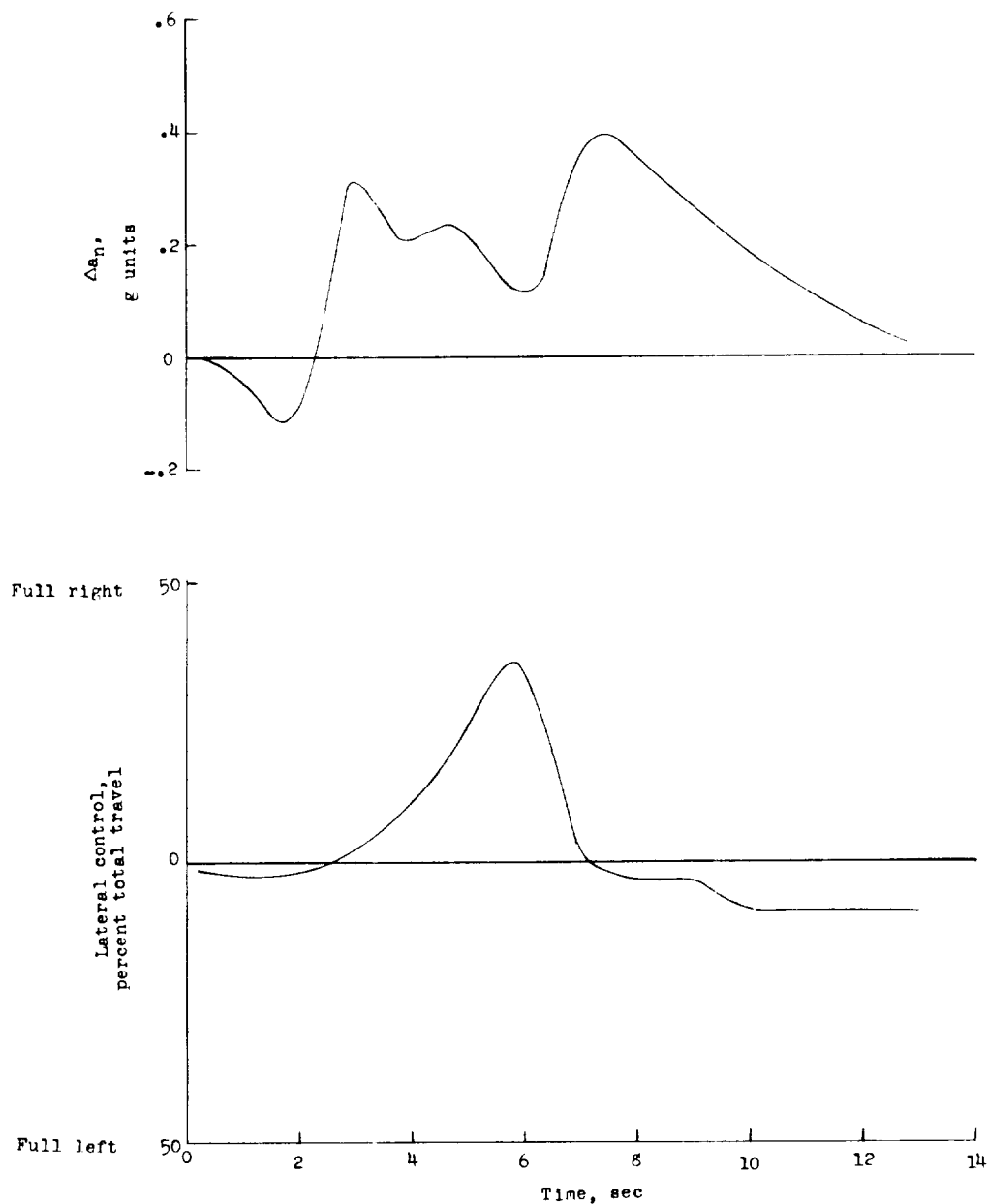


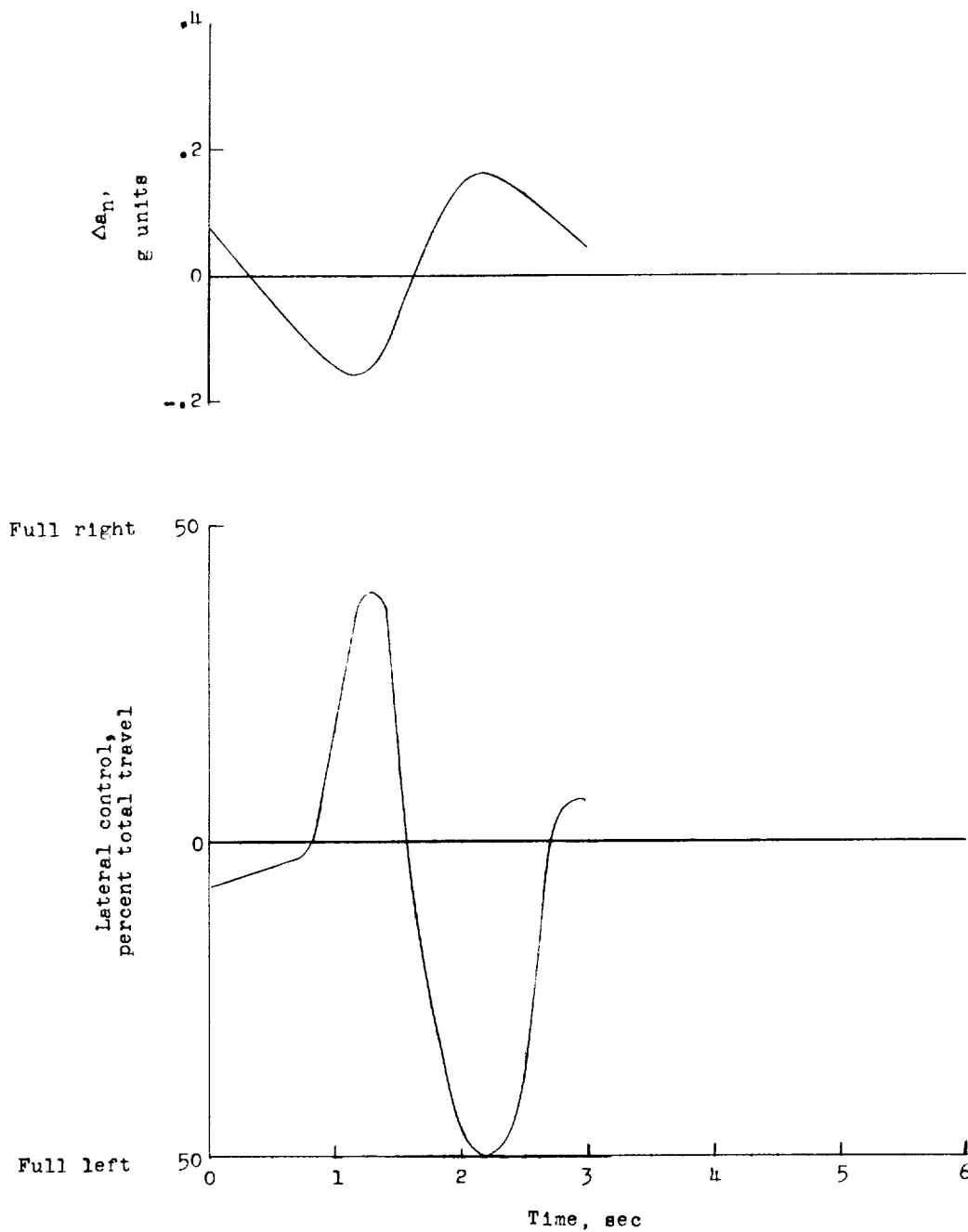
Figure 4.- Schematic diagram of the helicopter wake showing pictorially how the vortices roll up at the tips and expand downstream.

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(a) Penetration from 1,000 feet behind the helicopter and 50 feet below the helicopter flight path.

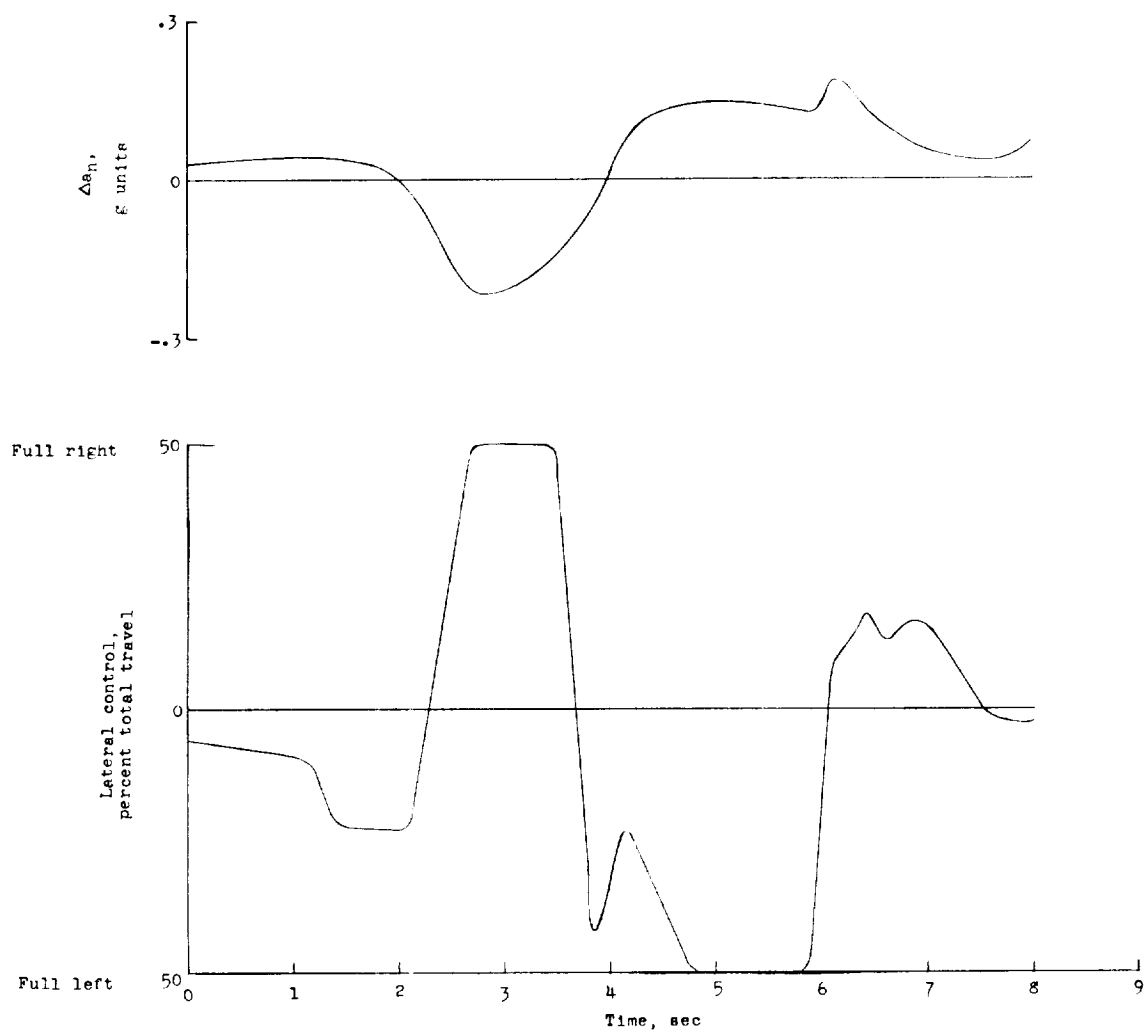
Figure 5.- Time-history plots of pilot's control response to prevent lateral upset of the test airplane following penetration into the helicopter wake. Penetration was executed from a gradual crossover course almost parallel to the helicopter course. Helicopter indicated airspeed, 40 knots; airplane indicated airspeed, 80 knots.



(b) Penetration from 1,000 feet behind the helicopter and 100 feet below the helicopter flight path.

Figure 5.- Continued.

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(c) Penetration from 1,000 feet behind the helicopter and 200 feet below the helicopter flight path.

Figure 5.- Concluded.

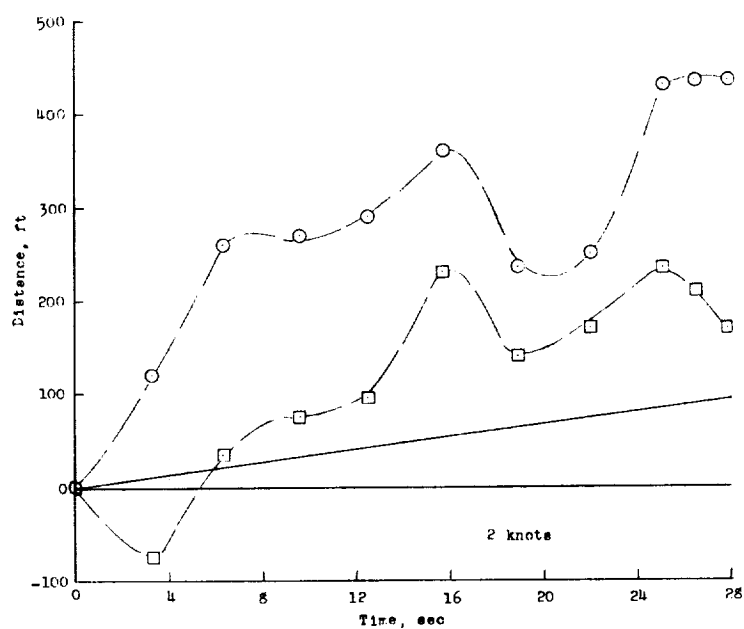
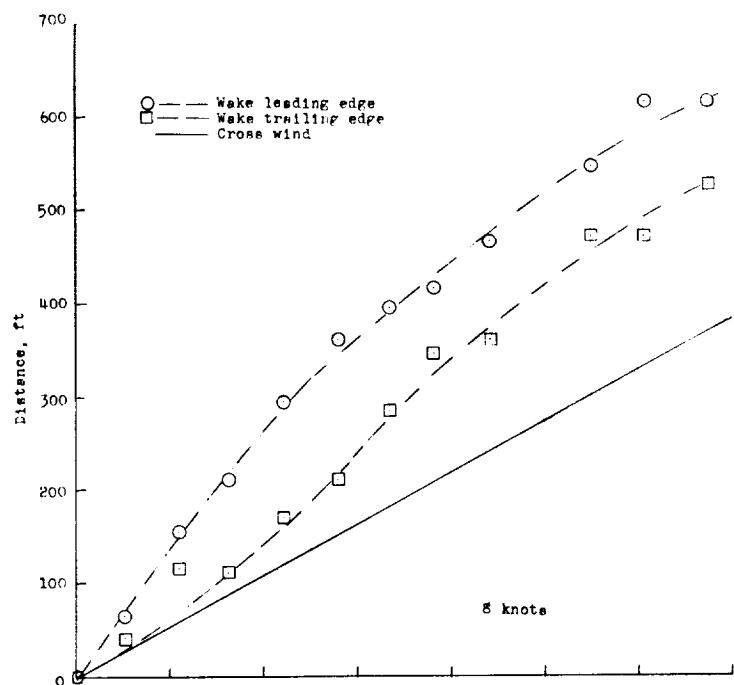


Figure 6.- Plots of smoke-wake drift under the influence of moderate surface cross winds. Helicopter indicated airspeed, 50 knots; altitude, 150 feet.





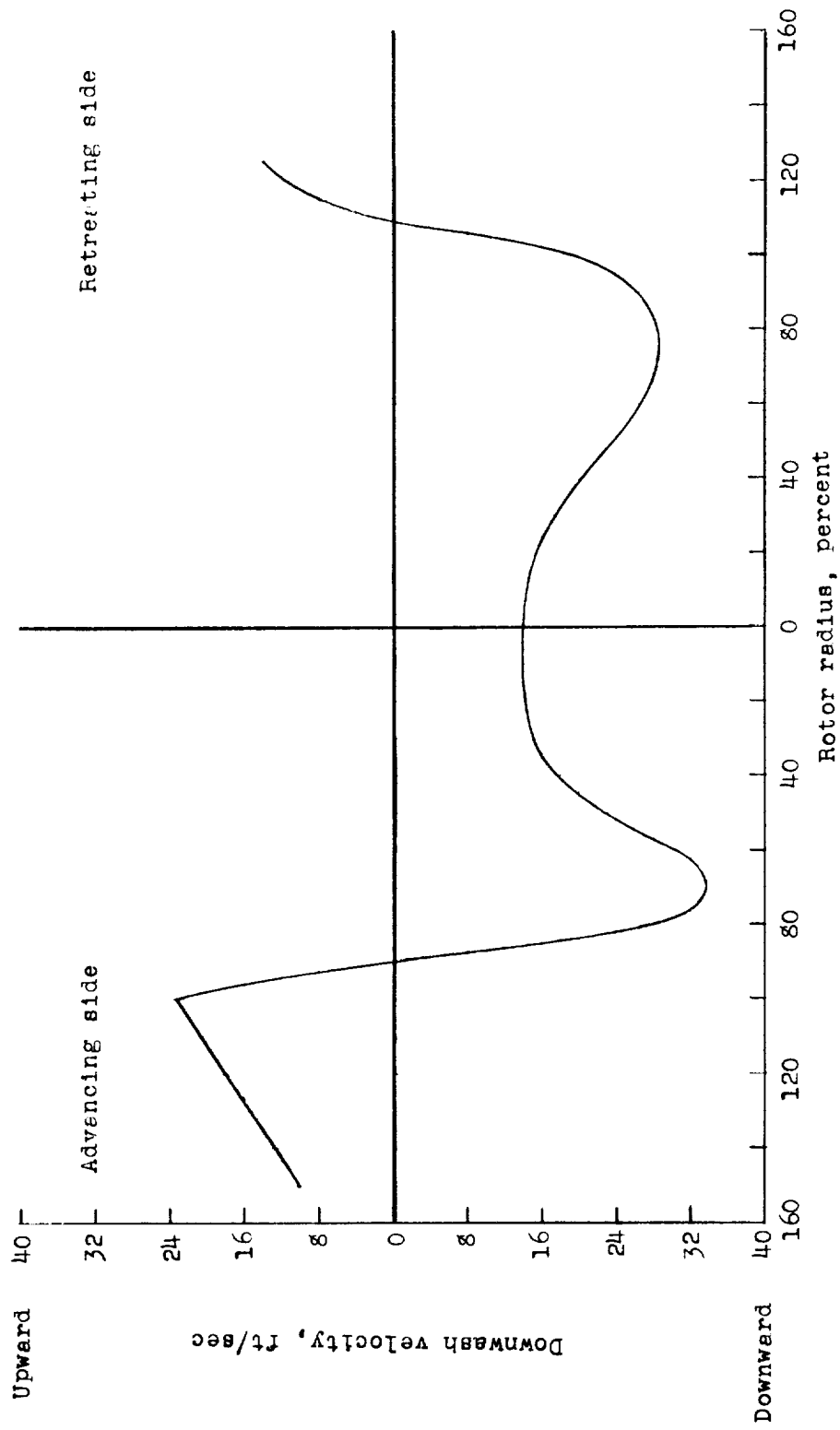


Figure 8.- Rotor downwash distribution in the plane of the vortex cores, according to the contour plot of figure 7(a) and as applied to the test helicopter.

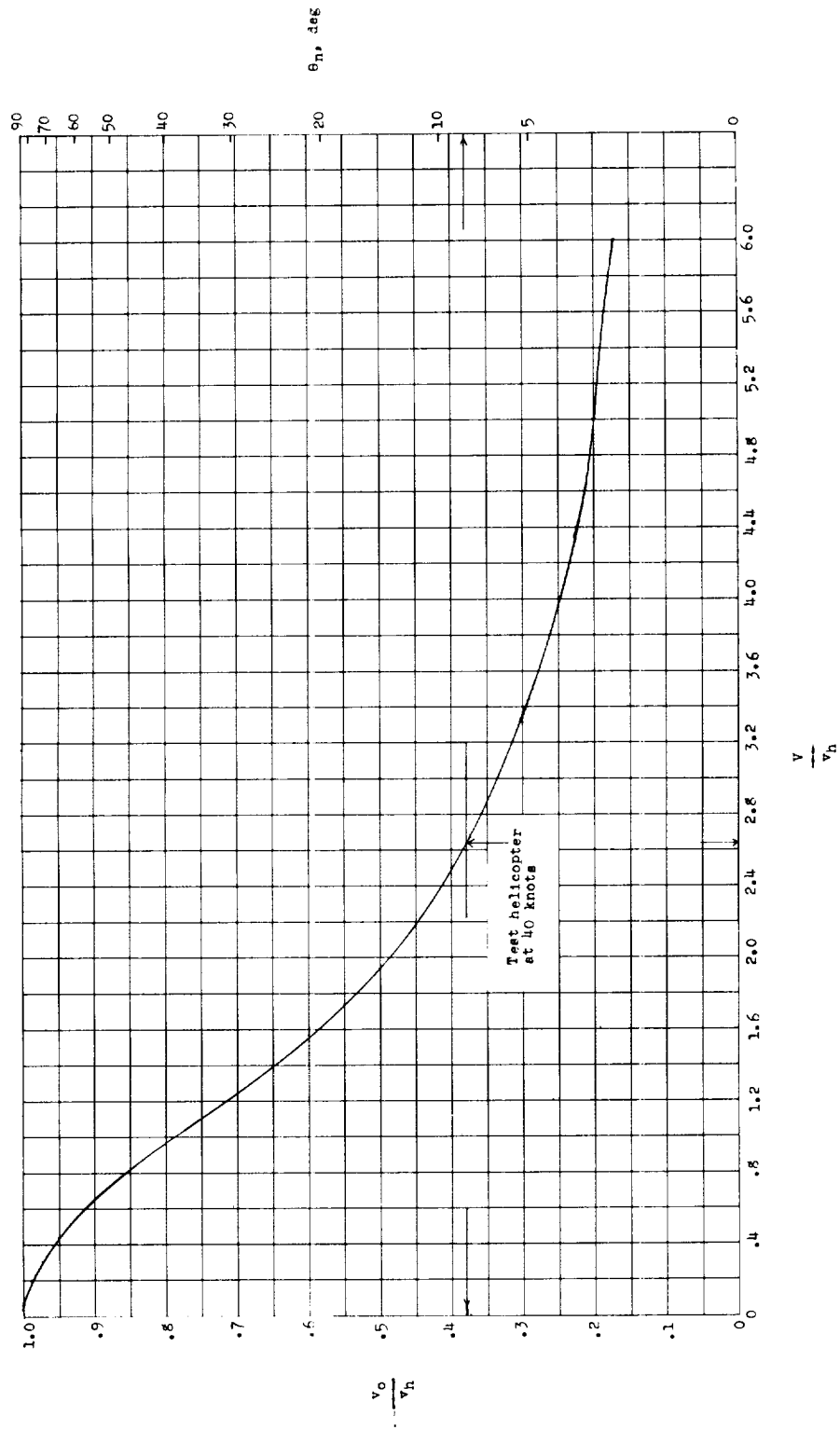


Figure 9.- Nondimensional values of the average vertical induced velocity as a function of forward velocity. Plot obtained from reference 6.





